NERRS Science Collaborative Progress Report for the Period 9/1/2012 through 2/28/2013

Project Title: A collaborative approach to address larval supplies and settlement as critical early life-history issues during restoration of native Olympia oysters (*Ostrea lurida*) in Coos Bay and the South Slough estuary

Principal Investigator(s): Dr. Steven Rumrill

Project start date: Nov 2010

Report compiled by: Steven Rumrill / John Bragg

Contributing team members and their role in the project:

Integration Leader: Frank Burris, Extension Watershed Educator
Oregon State University Extension Service
Gold Beach, OR
Role in project: Facilitation of interactions between the stakeholders (Olympia Oyster Restoration Advisory Committee) and project team members. Mr. Burris has expertise with community stakeholder discussions in rural environments, and will provide for integration and leadership through the joint fact-finding / structured decision-making process.

Co-Principal Investigators: Dr. Craig Young, Professor of Biology
University of Oregon / Oregon Institute of Marine Biology
Charleston, OR
Role in project: Director of OIMB and collaborating project scientist with particular expertise in the reproductive biology and larval ecology of marine and estuarine invertebrates. Dr. Young will serve as the primary graduate thesis advisor for one graduate student (module 1 / reproduction and reproductive output) supported by the project.

Dr. Alan Shanks, Professor of Biology
University of Oregon / Oregon Institute of Marine Biology
Charleston, OR
Role in project: Collaborating project scientist with particular expertise in larval behavior, dispersal, and tidally-driven transport in estuaries. Dr. Shanks will serve as the primary graduate thesis advisor for one graduate student (module 2 / larval supplies and dispersal) supported by the project.

Dr. Richard Emlet, Professor of Biology
University of Oregon / Oregon Institute of Marine Biology
Charleston, OR
Role in project: Collaborating project scientist with particular expertise in larval development, hydromechanics, larval settlement, and metamorphosis. Dr. Emlet will serve as the

primary graduate thesis advisor for one graduate student (module 3 / larval settlement and metamorphosis) supported by the project.

Jamie Doyle, Marine Community Development Leader
Oregon Sea Grant Extension Program (Coos County)
Myrtle Point, OR
Role in project: Work with project team to develop a series of presentations, fact sheets, briefing materials to ensure that the stakeholders and scientists share a common level of understanding about the biology and ecology of Olympia oysters. Ms. Doyle has expertise with marine resource policy and management, community education, and outreach, and she will provide assistance to the Integration Leader with the SDM process.

John Bragg, Communications Leader
Coastal Training Program Coordinator
South Slough National Estuarine Research Reserve
Charleston, OR
Role in project: Work to conduct regular and routine communications among members of the project team and the NERRS Science Collaborative, to compile and summarize discussion notes generated during OORAC meetings, serve as co-author of the NSC Biannual reports, and assist with development of presentations, fact sheets, and briefing materials. Mr. Bragg has expertise with condensation of technical research materials into summary sheets, and will provide an interface for the project with the South Slough National Estuarine Research Reserve. John will also provide assistance to the Integration Leader with the SDM process.

A. Progress overview: State the overall goal of your project, and briefly summarize in one or two paragraphs, what you planned to accomplish during this period and your progress on tasks for this reporting period. This overview will be made public for all reports, including confidential submissions.

Project Goal: The overall goal of this project is to investigate the importance of reproductive timing and output, larval supplies, estuarine retention time, settlement, and recruitment as factors that potentially limit recovery of self-sustaining populations of *Ostrea lurida* in Coos Bay and the South Slough estuary. Our specific objectives are to: (A) bring together a diverse group of stakeholders and user-groups to form an Olympia Oyster Recovery Advisory Committee (OORAC); (B) determine the suite of intrinsic ecological, reproductive, and early life-history factors that contribute to the success of Olympia oyster restoration efforts in Coos Bay/South Slough; and (C) integrate the perspectives and collective knowledge from resource agencies, academic investigators, mariculture operators, restoration practitioners, and recreational stakeholders during development of an Olympia Oyster Conservation and Recovery Strategy for Coos Bay.

Accomplishments: Members of the science team met on 7 Feb 2013 at the University of Oregon / Oregon Institute of Marine Biology (OIMB) to discuss the progress and winter work-

plans for the three graduate students. The students continued their thesis work that is focused on the reproductive biology and larval ecology of Olympia oysters (*Ostrea lurida*) in the Coos Bay estuary (Oregon). Mark Oates (MSC candidate; Dr. Craig Young thesis advisor) continued his investigation of gametogenesis, brooding, and brood release among populations of *O. lurida* in Coos Bay. Cate Pritchard (MSc candidate; Dr. Alan Shanks thesis advisor) is investigating the physical hydrodynamic characteristics of the greater Coos Bay estuary and how they influence the supplies, dispersion, export, and retention of *O. lurida* larvae. Rose Rimler (MSc candidate; Dr. Richard Emlet thesis advisor) is documenting the seasonal pattern of larval settlement, metamorphosis, survival, and growth at multiple locations throughout the Coos estuary. All three of the OIMB graduate students are supported by the NERRS Science Collaborative.

Over the past six months (Sep 2012 to Feb 2013) Mark Oates continued to conduct monthly collections of adult Olympia oysters and bimonthly measurements of multiple ambient water quality parameters (*i.e.*, temperature, salinity, chlorophyll) from two intertidal sites within Coos Bay (Haynes Inlet and Coalbank Slough). The oysters are measured, examined in the laboratory to determine gender (male, female, hermaphrodite), classify their level of gonad development, and dissected for paraffin histology and analysis of the gonadal tissues. Thin sections of the gonadal tissues are examined under a compound microscope, and the Reproductive Condition Index (*i.e.*, early gametogenesis, ripe gonad, partially spawned) is recorded for each individual oyster. Histological analysis of the oyster gonads is completed (*i.e.*, sex category, maturity stage, oocyte diameter), and the data have been compiled for the period from Jan to Dec 2012. Brooding Olympia oysters were observed over the period from Jul to Sep 2012, and brooded embryos and larvae were collected and quantified to develop an estimate of fecundity (i.e., number of brooded embryos and larvae per adult oyster). It is estimated that each brooding female oyster may release up to 250,000 veliger larvae.

Rose Rimler and Cate Pritchard worked together over the period from Sep 2012 to Feb 2013 to routinely monitor and analyze a set of integrated field experiments to assess the supplies and settlement of *Ostrea lurida* larvae at multiple locations within Coos Bay. Beginning in Jul 2012, a series of replicated ceramic settlement plates (attached to PVC pipe) and replicated larval settlement tubes (five per site) were out-planted into the soft sediments in the lower intertidal zone along the edges of the primary tidal channel at five locations: (A) Empire tideflats; (B) Haynes Inlet; (C) downtown Coos Bay; (D) Coalbank Slough; and (E) Catching Slough. Approximately every two weeks (until Dec 2012), the larval traps and settlement plates were recovered from the field and returned to the laboratory for examination and processing. Both the larval traps and settlement plates were replaced with new collectors at the time of recovery. In the laboratory, the contents of the larval traps and settlement plates are examined under a stereomicroscope, and the numbers of Olympia oyster (*O. lurida*) and Pacific oyster (*Crassostrea gigas*) larvae and spat are sorted, identified, enumerated, and measured.

Larval and post-larval oysters were observed in the traps and on the settlement plates on every sampling date over the period from 2 Aug to 11 Oct 2012. The greatest number of oyster larvae settled during mid-to late Aug at the Downtown Coos Bay study site where an average of 20-25 settlers per 50 sq. cm were observed on the ceramic tiles. Intermediate numbers of settlers were observed at Haynes Inlet, and a few settlers occurred at Coalbank Slough and Catching Sough. No settlers were observed at the Empire study site. Rose and Cate continued to monitor the larval traps and settlement plates every two-weeks through the end of Nov 2012 to ensure that their acquired datasets span the entire period of pre-settlement, early, peak, and diminished, and post-settlement for *O. lurida* in Coos Bay. Monitoring of oyster settlement was terminated after 22 Nov 2012 with the onset of winter storms.

Beginning in Jan 2013, Rose initiated a new field experiment designed to address the following question: *do young Olympia oyster survive and grow equally well in the different regions of Coos Bay?* She placed oysters of two size classes at four of the five study sites that were monitored for settlement in 2012. Because oyster larvae cannot be obtained until the spring, she used naturally-recruited juvenile and sub-adult oysters collected from one field site (Coalbank Slough). The Olympia oysters had recruited to bags of non-living Pacific oyster shell (*Crassostrea gigas*) that were deployed earlier (2011) in hanging bags to provide surfaces for larval settlement. The Olympia oysters were removed from the Pacific oyster shells, and attached to ceramic tiles with epoxy adhesive and bolted onto stakes placed in the low intertidal zone. "Small" (between 3 and 6 mm shell width) and "medium" (between 20 and 25 mm shell width) oysters were placed at Haynes Inlet and Coalbank Slough; "medium" oysters were placed at Downtown Coos Bay and Catching Slough. Growth and mortality of these oysters are measured monthly. The experiment will continue through early summer 2013. A similar experiment may be undertaken beginning in the late spring or early summer, using younger juveniles obtained from the Whiskey Creek Shellfish Hatchery.

Rose has also maintained a laboratory culture of *Ostrea lurida* larvae and early settlers (obtained from Matt Gray; Oregon State University / Hatfield Marine Science Center) and a culture of recently settled *Crassostrea gigas* spat (obtained from Lili Clausen; Silver Point Oyster Company). These laboratory cultures allow for side-by-side comparison of the appearance and morphology for early settlers of the two species, and help with the identification of the new settlers on the ceramic plates.

Cate Pritchard is focusing her investigation on differences in the supplies of Olympia oyster larvae along the marine-to-estuarine gradient of Coos Bay. In particular, she is using the combination of passive larval traps and settlement plates (monitored by Rose Rimler) to address the following questions: (1) *are early- and late-stage larvae supplied equally throughout the estuary?* (2) *are early- and late-stage larvae supplied to areas outside the range of adult oysters?* (3) *can water quality parameters such as temperature or salinity be used to predict larval abundance?* Larval traps collected between Jul and Sep 2012 indicate that neither early nor late-stage larvae were supplied equally throughout the estuary. Both stages of larvae exhibited their peak in abundance during the first sampling interval (July 19-Aug 2), and the greatest abundance of both stages occurred at the Downtown Coos Bay study site. Early-stage larvae were most abundant at Coalbank Slough, followed by Catching Slough, Haynes Inlet, and Empire. Late-stage larvae were most abundant in Downtown Coos Bay, followed by Haynes Inlet, Coalbank Slough, Catching Slough, and Empire. These patterns of larval abundance within stages and between sites continued for the remainder of the sampling season. It was common to observe no early-stage larvae or late-stage larvae in the samples collected from Empire. These preliminary results indicate that early- and late-stage larvae are not supplied equally throughout the estuary.

Cate also continued to collect time-series measurements for several ambient water parameters that may be important to the supplies of Olympia oyster larvae within the estuary. She maintained a series of dataloggers (water level, temperature, salinity) deployed at five strategic points in the estuary to record measurements of water temperature and salinity throughout the seasonal period of brood release, larval dispersion, and settlement. Ambient water temperature and salinity were measured every 10 minutes at each site using HOBO data loggers.

The most riverine site (Catching Slough) experienced extreme salinity shifts with the tides (rage 0-22 ppt within a single day). Ambient water temperatures were elevated (up to 22°C) through the end of Aug 2012. However, although larvae were present in the water column, very little settlement was observed, and there are currently no known adult populations at this site. Such large shifts in the daily salinities would likely cause physiological stress, even for a tolerant estuarine organism like the Olympia oyster. Both the Coalbank Slough and Downtown sites are characterized by relatively stable, moderately saline waters (~16-20 ppt), although larger shifts in salinity occurred with the onset of seasonal rains, and temperature is relatively stable (generally below 20°C). Larval supplies and settlement at both the Coalbank Slough and Downtown sites were generally high, with the Downtown site having the highest abundances of both early- and late-stage larvae and settlers through all sampling dates. Despite the lower physiological stresses associated with these stable environments, the relationship between larval supply, settlement, and water quality parameters such as temperature and salinity may be complicated by proximity to reproductive adult populations or hydrodynamic mechanisms of retention.

The Haynes Inlet study site was characterized by very stable high-salinity water (~25 ppt), with moderate variability in temperature (14-20°C). Larval supplies and settlement were both were intermediate at Haynes Inlet. The most marine-influenced site (Empire) exhibited very stable salinities (25-30 ppt) and low temperatures (9-14°C). However, the very low larval supply at Empire could be influenced by hydrodynamic barriers in the upper estuary, retaining larvae and preventing delivery toward the mouth of the bay. Future work is needed to address these complications, and growth and mortality studies could help us understand the physiological stresses that these regimes influence.

Earlier in the project (Jul-Aug 2011), NSC Principal Investigator Steve Rumrill (South Slough NERR / Oregon Department of Fish and Wildlife) worked with an Oregon Sea Grant Scholar (Joanne Choi; Yale University) to develop, construct, and deploy a series of small-scale, modular, experimental, artificial substrata that were designed to enhance localized recruitment of Olympia oysters. The OLY-ROCS (Olympia Oyster - Restoration of Oysters on Concrete Substrata) were deployed in sets of six replicate units at two locations in Coos Bay (Haynes Inlet and Isthmus Slough; Aug 2011). In Dec 2012 and Jan 2013, Steve conducted a field assessment of the OLY-ROCS and found evidence that larval settlement and successful recruitment had occurred over the summer/fall of 2012 at both the Isthmus Slough and Haynes Inlet sites. Settlement and survival on the OLY-ROCS were greater at the Isthmus Slough site and lower at the Haynes Inlet site. Observation of variability in recruitment success on the OLY-ROCS (*post-facto* evidence based on shell size-frequencies), coupled with observations of differential larval supplies (in larval traps) and settlement (on the ceramic plates), indicates that larval settlement has been consistent in the upper mesohaline region of Coos Bay where tidal waters are typically retained within the estuary, but more variable in the mid-region at Haynes Inlet where tidal waters are more completely flushed.

B. Working with Intended Users:

- Describe the progress on tasks related to the integration of intended users into the project for this reporting period
- What did you learn? Have there been any unanticipated challenges or opportunities?
- Who has been involved?
- Has interaction with intended users brought about any changes to your methods for integration of intended users, the intended users involved, or your project objectives?

- How do you anticipate working with intended users in the next six months?

Integration of Input from Intended Users: Steve Rumrill met individually and in small groups with several members of the Olympia Oyster Restoration Advisory Committee (OORAC) over the reporting period (Sep 2012 – Feb 2013) to discuss the progress made by the graduate students and the implications of their findings toward Olympia oyster restoration and other oyster recovery efforts in Oregon estuaries.

OORAC members Alicia Helms (South Slough NERR) and David Landkammer (Oregon Sea Grant – Aquaculture Extension) toured through the experimental Olympia oyster out-planting areas within the South Slough (Younker Point; Long Island Point; Sep 2012). The tour allowed David Landkammer to become familiar with on-the-ground efforts and techniques to restore Olympia oysters in habitats where larval supplies and the availability of adequate hard substrata appear to be limiting factors, and he made several suggestions about the need for new research. The tour of the Olympia oyster restoration sites was featured in an outreach article published by Oregon Sea Grant (see Appendix II). Rumrill also met with the new Lead Scientist/Research Coordinator for South Slough NERR (Larry Basch; 7 Feb 2013) to welcome him to his new position, to provide an update on the history of Olympia oyster research in Coos Bay and South Slough, to introduce him to the three OIMB graduate students supported by the NERRS Science Collaborative project (M. Oates, R. Rimler, C. Pritchard), to describe their thesis research, and to discuss the prospects for future research efforts that focus on restoration and recovery of Olympia oyster populations.

OORAC members Laura Hoberecht (NOAA Aquaculture Center), Brett Dumbauld (US Department of Agriculture / Agriculture Research Service), Ken Phippen (NOAA / NMFS), and several others met with Steve Rumrill (11 Feb 2013) to discuss the history of research and field experiments designed to investigate the environmental impacts of oyster mariculture operations (*Crassostrea gigas*, Ostrea lurida, *C. sikamea*) on estuarine habitats and communities. The representatives from NOAA/NMFS (Ken Phippen and Michelle Mullin) also met with Steve Rumrill (14 Feb 2013) to discuss possible permit requirements for a new commercial Olympia oyster mariculture lease plat located in Netarts Bay, OR (see unanticipated opportunity, below).

OORAC member Xin Liu (Oregon Oyster Farm) held several phone conservations over the past few months with Steve Rumrill to discuss the potential role of his commercial mariculture operations in the broodstock recovery and restoration of Olympia oysters. Rumrill also met with OORAC member Sue Cudd (Whiskey Creek Shellfish Hatchery) in Tillamook (Nov 2012) to discuss the impacts of ocean acidification on operations within the shellfish hatchery, and to gain a better understanding of the differential impacts of OA on the embryos and larvae of Olympia oysters and pacific oysters (see unanticipated opportunity, below).

The OORAC identified the need for a new NSC fact-sheet to clarify and summarize the state agency jurisdiction over management of commercial oyster cultivation activities in Coos Bay. In response to this request, a new NSC fact-sheet was developed titled "*Regulations regarding the commercial mariculture of oysters in Oregon bays and estuaries*" (see Appendix III). The NSC fact-sheet describes the specific regulatory authority of the Oregon Department of Agriculture to permit and manage commercial oyster cultivation and harvest activities within a series of classified shellfish growing areas. The NSC fact-sheet also provides a summary of the statewide jurisdiction held by the Oregon Department of Fish and Wildlife to prohibit or allow recreational harvests of Olympia oysters within the waters of the state. OORAC Members Jim Johnson and John Byers (OR Department of Agriculture / Shellfish Program) received an early draft of the NSC fact-sheet for their editorial review.

Steve Rumrill worked during Feb 2013 with OORAC members Laura Hoberecht (NOAA Aquaculture Center) and Dick Vander Schaaf (Coastal Conservation Leader / The Nature Conservancy), and with representatives from the NOAA Restoration Center (Laurel Jennings, Summer Morlock) to develop a technical-transfer proposal to support the next West Coast Native Oyster Restoration Workshop (WCNOW). A series of three WCNOWs were held previously along the Pacific coast (2006, 2007, 2010) that focused specifically on the status of sensitive populations, technical hurdles, ecological factors, and practical steps that can be taken to foster restoration and recovery of Olympia oyster (*Ostrea lurida*) populations along the shorelines of California, Oregon, Washington, and British Columbia. These workshops served as pivotal events to catalyze discussions and debate regarding the current and future actions to help guide recovery efforts for Olympia oyster populations along the Pacific coast. If the request for NOAA funds is successful, WCNOW #4 will be a 3-day workshop (2 days of presentations/break-out groups and 1-day field trip) held in Portland, OR during Sep of 2013. The WCNOW will provide an ideal venue for the graduate students, scientists, and stakeholders working with support from the NSC to share their research and experiences with their colleagues from the South Slough NERR, Elkhorn Slough NERR, and San Francisco Bay NERR.

Unanticipated challenges and opportunities: The Oregon Department of Agriculture and Oregon Department of Fish and Wildlife recently signed a court-mediated agreement to allow the commercial cultivation of native Olympia oysters within a private lease area located in Netarts Bay, OR. ODFW currently prohibits the recreational harvest of Olympia oysters from public waters, but ODFW does not have regulatory authority for the cultivated oysters (including Olympia oysters), clams, and mussels that are grown for commercial purposes in leased plats. OORAC member Ken Phippen (and Michelle Mullin, NMFS coastal ecologist) contacted Steve Rumrill to seek guidance on the establishment of commercial-scale Olympia oyster beds in the estuarine environment, and to discuss design options for the Olympia oyster mariculture area to minimize disturbance to established eelgrass (*Zostera marina*) and other estuarine organisms. Deliberate establishment of a commercial mariculture grow-out bed of Olympia oysters in Netarts Bay poses an unexpected opportunity to incorporate recent findings generated by the current NSC project into the application of a pending regulatory permit. In addition, establishment of the commercial Olympia oyster mariculture plat lease also provides a new opportunity to investigate factors that contribute to survival, growth, and reproduction of this species on a meso-scale that is substantially larger than the small-scale restoration plots. It is possible that the commercial mariculture lease area for Olympia oysters will be established during the summer of 2013.

Changes to methods of integration: Members of the project team have been largely effective in their meetings with the stakeholders in small groups or on a one-on-one basis over the last several months (Sep 2012 to Feb 2013). The stakeholders continue to provide input into the science conducted by the OIMB graduate students and to share their perspectives about recovery and restoration of Olympia oyster populations. For example, OORAC members from the Port of Coos Bay (Elise Hamner; Community Affairs Coordinator) and the US Army Corps of Engineers (Kate Groth; Oregon South Coast Navigational Channel Coordinator) have raised questions about the role of sedimentation on larval settlement by Olympia oysters. It is likely that OIMB graduate student Rose Rimler will be able to design and conduct a laboratory and field experiment to address this question once larvae become available from the Whiskey Creek Shellfish Hatchery. We have addressed this change to the method of integration by holding one-on-one and small group discussions over the reporting period with members of the commercial mariculture industry (Xin Liu, Oregon Oyster Farm; and Sue Cudd, Whiskey Creek

Shellfish Hatchery), and by meeting with the NOAA Aquaculture Center (Laura Hoberecht; Pacific Regional Coordinator) and Oregon Sea Grant (David Landkammer; Aquaculture Extension Agent). Steve Rumrill also met with OORAC members Alicia Helms, Mike Graybill, Brett Dumbauld, Ken Phippen, Dick vander Schaaf, Jim Johnson, Chris Langdon, and Andy Lanier on separate occasions to discuss the role of oyster reproduction, larval supplies, and settlement in the recovery of Olympia oysters in Oregon estuaries. Information gained from these individual discussions and meetings is shared with members of the project team and scientists during graduate thesis advisory committee meetings (*i.e.*, 7 Feb 2013) and through direct phone calls and email correspondence.

During the next six months: During the next six months we will maintain periodic contact with intended users and stakeholders to: (1) provide NSC fact-sheet updates on the new scientific assessments of reproduction and larval ecology of Olympia oysters in Coos Bay; (2) work to better integrate the three components of the reproductive biology (Module 1 / reproduction and brooding; Module 2 / larval supplies and dispersal; Module 3 / larval settlement) into the framework for the local Olympia Oyster Conservation and Recovery Plan; (3) continue to use the feedback, input, and other comments provided by OORAC to further refine how the data sets and output generated by the graduate students will contribute to the local conservation plan for Olympia oysters in Coos Bay; (4) distribute a new NSC fact-sheet to clarify and summarize the agency jurisdiction over management of commercial oyster cultivation activities in Coos Bay; (5) bring the members of OORAC together as a group to discuss development of the local Olympia oyster conservation plan and recovery strategy for Coos Bay; and (6) secure funding and finalize plans for the next West Coast Native Oyster Restoration Workshop (proposed for Portland, OR (Sep 2013; pending federal support from the NOAA Aquaculture Center).

C. Progress on project objectives for this reporting period:

- Describe progress on tasks related to project objectives for this reporting period.
- What data did you collect?
- Has your progress in this period brought about any changes to your methods, the integration of intended users, or the project objectives?
- Have there been any unanticipated challenges, opportunities, or lessons learned?
- What are your plans for meeting project objectives for the next six months?

Progress and Data Collection: Over the past six months (Sep 2012 to Feb 2013) the three graduate students from the Oregon Institute of Marine Biology (Mark Oates, Cate Pritchard, Rose Rimler) continued their thesis work on the reproductive biology and larval ecology of Olympia oysters in the Coos Bay estuary. Input received from the OORAC was incorporated earlier into the objectives and design for the new science activities conducted by the students. Several different types of data were collected by members of the science team over the fall and winter months. Mark Oates (Module 1/ reproduction) continued the monthly collection of adult Olympia oysters, and the bimonthly measurements of multiple ambient water quality parameters from two intertidal sites within Coos Bay (Haynes Inlet and Coalbank Slough). He prepared histological slides, and analyzed the gonadal tissues to characterize seasonal changes in the different stages of oogenesis, spermatogenesis, gender switching, and brooding for two local populations of Olympia oysters. Mark also enumerated the numbers of embryos and brooded larvae to develop an estimate of fecundity. Cate Pritchard (Module 2 / larval supplies and dispersal) continued to generate new data to describe seasonal variability in ambient water parameters, and to deploy and recover a series of passive larval traps to characterize the abundance, supplies, and dispersal of Olympia oyster larvae at five strategic locations in Coos

Bay. Rose Rimler continued to conduct monthly assessments of the settlement, survival, and growth of Olympia oysters that recruit onto a series of paired ceramic plates deployed at five sites throughout Coos Bay estuary. The graduate students continued to maintain a series of automated dataloggers to record ambient water parameters (*i.e.*, temperature, salinity, water level) at strategic points in Coos Bay, and the South Slough NERR continued to collect time-series measurements of estuarine water quality parameters (estuarine water temp, sal, cond, pH, DO, Chl-a, turb) at several locations along the estuarine gradient of the South Slough.

Changes in methods and integration of intended users: OORAC members from the Port of Coos Bay (Elise Hamner; Community Affairs Coordinator) and the US Army Corps of Engineers (Kate Groth; Oregon South Coast Navigational Channel Coordinator) have raised questions about the role of sedimentation on larval settlement by Olympia oysters. It is likely that OIMB graduate student Rose Rimler will be able to design and conduct a laboratory and field experiment to address an important question about the effects of sedimentation on larval settlement (in May or June after oyster larvae become available from the Whiskey Creek Shellfish Hatchery).

Unanticipated challenge, opportunities, and lessons learned: Recent research activities led by NOAA and academic scientists from Oregon State University (including OORAC member Dr. Chris Langdon) have placed an intense spotlight on the threats to native and cultivated shellfish due to elevated pCO2 concentrations in the nearshore ocean waters off of Oregon and northern California. Wind-driven upwelling of cold, often hypoxic, ocean waters, coupled with ocean acidification (OA) and shifts in the saturation state for the carbonate shells of larval bivalves, brings the coastal populations of adult oysters and their planktonic larval stages into contact with waters that can be corrosive to the formation of larval shells. Damage to oyster larvae from the combined effects of hypoxia and OA can be fatal, and several media articles have recently reported that larval oysters serve as a "canary in a coal mine" to forecast the detrimental impact of OA in Pacific northwest coastal waters. However, despite several years of very poor success with rearing the larvae planktonic larvae of Pacific oysters (*Crassostrea gigas*) in the hatcheries (attributed to OA), the planktonic larvae of *Ostrea lurida* have routinely survived and settled successfully in Coos Bay (near the upwelling center at Cape Arago). It appears that the larvae from the native Olympia oyster may be less susceptible to the combined effects of hypoxia and OA in comparison with larvae from the non-indigenous Pacific oyster. The recent spotlight on OA as a contributing factor in the poor reproductive success of oysters places an unanticipated emphasis on the requirement to gain an improved understanding of the suite of biophysical conditions that contribute to continued success of reproduction and larval settlement for the recovering populations of Olympia oysters in Coos Bay.

The South Slough NERR / System-wide Monitoring Program (SWMP) has recently gained grant support and in-kind contributions that will allow for the addition of automated PCO2 sensors, fine-scale pH measurements, and calculations of carbonate saturation states to the suite of standard ambient water parameters recorded by dataloggers. These new additions to the characterization of ambient water masses will present an excellent opportunity to compare and contrast the dynamics of larval production and settlement for native Olympia oysters in Coos Bay/South Slough with that of non-indigenous Pacific oysters raised in a hatchery setting. It is likely that the ongoing and collaborative work carried out by the graduate students at OIMB and the time-series of monitoring records generated by the South Slough NERR will serve as a catalyst for future research into the potential and realized impacts of OA and hypoxia on native and non-native shellfish in

Pacific northwest estuaries. The ongoing research supported by the NSC will pay dividends in the future

For example, the opportunity to apply NERRS /SWMP data to investigate the links between OA and success of shellfish populations was recently recognized by the California Current Acidification Network (C-CAN). C-CAN is a collaboration that brings together scientists, industry representatives, managers, regulators, NGOs, and other stakeholders to increase our understanding about acidification of coastal, estuarine, and offshore waters and its effects on biological resources. C-CAN published their vision for development of the west coast network for monitoring marine acidification and its linkage to biological effects in Feb 2013, and the C-CAN workplan includes three priority participant groups that are targeted for new partnerships. The priority target organizations are: (1) shellfish hatcheries and harvest areas; (2) wastewater and stormwater dischargers; and (3) National Estuarine Research Reserves, coastal laboratories, and aquaria. More specifically, C-CAN (2013) will take actions to promote and provide incentives for the improvement of the NERRS / SWMP to include measurement of parameters to allow precise determination of aragonite saturation states that are relevant to shell formation in oysters and other shellfish.

Plan for the next Six Months: During the next six months we will maintain periodic contact with intended users and stakeholders to: (1) provide NSC fact-sheet updates on the new scientific assessments of reproduction and larval ecology of Olympia oysters in Coos Bay; (2) work to better integrate the three components of the reproductive biology (Module 1 / reproduction and brooding; Module 2 / larval supplies and dispersal; Module 3 / larval settlement) into the framework for the local Olympia Oyster Conservation and Recovery Plan; (3) continue to use the feedback, input, and other comments provided by OORAC to further refine how the data sets and output generated by the graduate students will contribute to development of the local conservation plan for Olympia oysters in Coos Bay; (4) distribute a new NSC fact-sheet to clarify and summarize the agency jurisdiction over management of commercial oyster cultivation activities in Coos Bay; (5) bring the members of OORAC together as a group to discuss development of the local Olympia oyster conservation plan and recovery strategy for Coos Bay; and (6) secure funding and finalize plans for the next West Coast Native Oyster Restoration Workshop (proposed for Portland, OR (Sep 2013; pending federal support from the NOAA Aquaculture Center) that will include a special pre-workshop meeting and exchange between the scientists, students, and staff affiliated with the SSNERR, ESNERR, and SFBNERR who are actively engaged in NERRS Science Collaborative projects that focus on Olympia oysters.

D. Benefit to NERRS and NOAA: List any project-related products, accomplishments, or discoveries that may be of interest to scientists or managers working on similar issues, your peers in the NERRS, or to NOAA. These may include, but are not limited to, workshops, trainings, or webinars; expert speakers; new publications; and new partnerships or key findings related to collaboration or applied science.

- Graduate students supported by the NSC project delivered poster presentations during the Heceta Head Coastal Conference (Florence, OR; 27 Oct 2012)
    - C. Pritchard / Where should Olympia oyster restoration be focused in the Coos Bay estuary?
    - R. Rimler / Larval settlement and post-settlement mortality as determinants of spatial distribution of Olympia oyster populations in Coos Bay

- Graduate students supported by the NSC project delivered poster presentations during the Western Society of Naturalists conference (Seaside, CA; 8-11 Nov 2012):
    - C. Pritchard, R. Rimler, A. Shanks / larval dispersal of the Olympia oyster (*Ostrea lurida*) in the Coos Bay estuary
    - R. Rimler, C. Pritchard / Larval settlement and post-settlement mortality as determinants of spatial distribution of Olympia oyster populations in Coos Bay, OR

- Members of the NSC science team delivered a series of Skype seminars/WebEx presentations during the SSNERR/GTMNERR EcoGeek Series: Reduce, Reuse, Recycle, and Restore:
    - S. Rumrill / Bringing the Olympia oyster back to Oregon's Coos Bay: Population recovery, habitat enhancement, and reproductive ecology of Olympia oysters (*Ostrea lurida*) in Coos Bay, OR (16 Jan 2013)
    - M. Oates / Observations of gonad structure and gametogenic timing in a recovering population of *Ostrea lurida* (20 Feb 2013)
    - C. Pritchard / Variability in supplies of Olympia oyster larvae along the estuarine gradient of Coos Bay (20 Feb 2013)
    - R. Rimler / Larval settlement and post-settlement mortality as determinants of spatial distribution of Olympia oyster populations in Coos Bay (20 Feb 2013)

- An article that highlights the Olympia oyster restoration work undertaken by the South Slough NERR was published by Oregon State University / Terra Magazine (Jan 2013; http://oregonstate.edu/terra/2013/01/south-slough/) see Appendix II

- New NSC Fact-sheet: "*Regulations regarding the commercial mariculture of oysters in Oregon bays and estuaries*" see Appendix III

- Updated NSC Fact-sheet: *"Observations of gonad structure and gametogenic timing in a recovering population of Olympia oysters"* see Appendix III

- Updated NSC Fact-sheet: "*Larval settlement and post-settlement mortality as determinants of spatial distribution of Olympia oyster populations in Coos Bay*" see Appendix III

- Updated NSC Fact-sheet: *"Larval supplies as a critical factor in the recovery of native Olympia oysters in Coos Bay"* see Appendix III

E. Describe any activities, products, accomplishments, or obstacles not addressed in other sections of this report that you feel are important for the Science Collaborative to know.

- The project PI (Steve Rumrill) and several members of the OORAC (Laura Hoberecht, David Landkammer, Chris Langdon, Brett Dumbauld) continue to work with members from private industry (*i.e.*, Pacific Coast Shellfish Growers Association) on development of the Oregon Shellfish Initiative. This cooperative and collaborative initiative is designed to help meet many of the goals of the National Shellfish Initiative, and will likely include a component that is focused on enhancement, restoration, and recovery of Olympia oyster populations in Oregon estuaries.

- The project PI (Steve Rumrill) participated in a review of the “sensitive” species that are afforded some level of protection under the Oregon sensitive Species Rule (OAR 635-100-0040). Considerations about merging the Oregon Conservation Strategy with the Oregon Sensitive Species List are relevant to development of the conservation strategy for Olympia oysters, and it is possible that merger process may include addition of Olympia oysters to the Oregon Sensitive Species List.

Appendix I. Photographs of field work, dissection of Olympia oysters, and deployment of marked oysters attached to ceramic plate

Figure 1. Mark Oates (OIMB graduate student) deploys a CTD multi-parameter datalogger in the estuarine waters of Coos Bay adjacent to a population of Olympia oysters at the Haynes Inlet study site.

Figure 2. Adult *Ostrea lurida* dissected to sample gonadal tissues for the determination of gender, reproductive condition, and stage of gametogenesis.

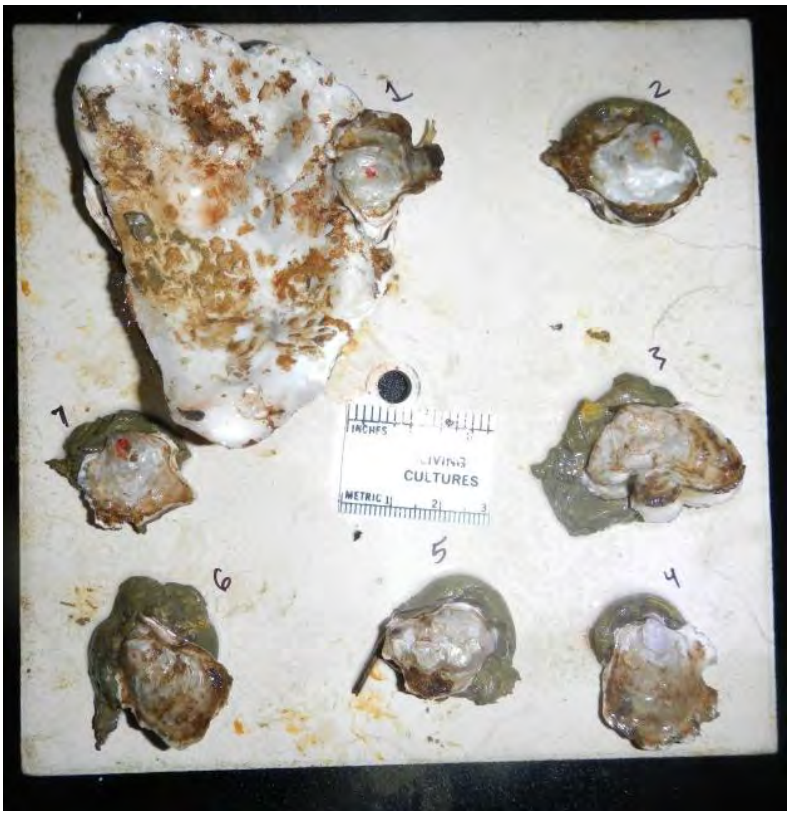


Figure 3. Individually-marked Olympia oysters attached with epoxy to ceramic plate. The marked oysters will be deployed into the field, recovered periodically, and re-measured to determine rates of growth.

Figure 4. Modular cement paving stone with new recruits of Olympia oysters. The OLY-ROCS were colonized over the late summer and fall of 2012 by a new generation of oysters, and they co-exist with eelgrass (*Zostera marina*) in the soft-sediment habitat at Isthmus Slough.

Figure 5. New recruits of Olympia oysters (*Ostrea lurida*) that have settled onto a non-living shell from the Pacific oyster (*Crassostrea gigas*) at Isthmus Slough.

Appendix II. An article that highlights the Olympia oyster restoration work undertaken by the South Slough NERR was published by Oregon State University / Terra Magazine (Jan 2013; http://oregonstate.edu/terra/2013/01/south-slough/)

OREGON STATE UNIVERSTY / TERRA MAGAZINE

- By Lee Sherman
- Posted on January 31st, 2013

Oregon State University master naturalist volunteers Anne Marie Farell-Matthews and Philip Matthews cut open sacks of native Olympia oysters and spread them on a muddy flat at Oregon's South Slough National Estuarine Research Reserve near Charleston. (Photo: Lynn Ketchum)

COOS BAY – Lots of people fantasize about appearing on *American Idol* or *Wheel of Fortune*. But *Oregon Field Guide*? Not so much — that is, unless you happen to be Anne Farrell-Matthews and Philip Matthews. Whether they're heaving bags of oysters around a sandbar or hauling groundwater monitors across a salt marsh, this pair of Oregon Master Naturalists could easily imagine OPB TV host Steve Amen showing up with a video crew. For the Coos Bay couple, joining in on ecosystem science and restoration is that glamorous.

So how is it that this hip couple in their 40s gets all excited about red tree voles, beaver scat and shimmy worms? Why would a general contractor and a graphic designer get up at 5 a.m. to wade around in the muck trying to save native oysters? Why would a pair of avid surfers forego great waves to study physical oceanography and the Cascadia Subduction Zone late into the night?

Partly because the South Slough runs through their veins. Philip tramped these mudflats and salt marshes relentlessly as a kid, his Irish setter Britta beside him. Anne came to Coos Bay later, at 19, from landlocked Denver where her bedroom walls had been plastered with whale posters. Finally, she felt like she could breathe. Together, they've explored every twist and tangle of the slough, which became the nation's first national estuarine research reserve in the 1970s.

The other answer is more cerebral. It has to do with making amends and taking ownership. It has to do with helping to heal the landscape they love, a landscape that has been stressed by overharvesting, pollution and population growth over the past century and a half.

Philip's motives are particularly personal. "I'm half French, half redneck," he likes to joke. Describing his mom's family, the French side of the clan, as "extreme environmentalists," he hammers home his point by saying, "My uncle once chained himself to City Hall to protect shorebirds from hunters." It's his dad's side

Appendix III. NSC fact-sheets

University of Oregon – Oregon Institute of Marine Biology / Charleston, OR

Regulations regarding the commercial mariculture of oysters in Oregon bays and estuaries

Project Title:
A collaborative approach to address reproduction, larval supplies, and settlement during recovery of native Olympia oysters

Location:
Coos Bay, Oregon

Goal:
Generate new science to support development of a conservation and recovery plan for Olympia oyster populations throughout Coos Bay

Partners:
Oregon Institute of Marine Biology; South Slough National Estuarine Research Reserve; Oregon State University; Oregon Sea Grant; Oregon Department of Fish and Wildlife

Timeline:
Nov 2011 to Sep 2013

Commercial mariculture of oysters in Oregon:

In Oregon, the commercial cultivation of oysters, clams, and mussels is designated as an agricultural activity that falls within the regulatory authority of the Oregon Department of Agriculture. By statute, the term "oyster" applies to living oysters and oyster larvae, as well as oyster cultch (living juveniles attached to non-living shells) and oyster shells. Several different species of oysters are cultivated in Oregon's bays and estuaries, including Pacific oysters (*Crassostrea gigas*) , Kumamoto oysters (*Crassostrea sikamea*), and native Olympia oysters (*Ostrea lurida*). It is unlawful to import oysters into Oregon for the purpose of planting and commercial cultivation without first obtaining a permit issued by the Oregon Department of Agriculture.

Oregon Department of Agriculture:

The Oregon Department of Agriculture (ODA) may issue permits to import oysters into Oregon waters when it has been established that a qualified person or agency will inspect the oysters and certify that they are free of diseases, infestation by pests or pathogens, or any substances that might endanger shellfish. Each commercial farmer, harvester, distributor, and processor who handles oysters for human consumption must obtain a Shellfish Sanitation Certificate from the ODA (Oregon Revised Statutes 622.020).

Pacific oyster (*Crassostrea gigas*)

Kumamotu oyster (*Crassostrea sikamea*)

Olympia oyster (*Ostrea lurida*)

University of Oregon – Oregon Institute of Marine Biology / Charleston, OR

Observations of gonad structure and gametogenic timing in a recovering population of Olympia oysters

Mark Oates, Oregon Institute of Marine Biology

Project Title:

A collaborative approach to address reproduction, larval supplies, and settlement during recovery of native Olympia oysters

Location:

Coos Bay, Oregon

Goal:

Generate new science to support development of a conservation and recovery plan for Olympia oyster populations throughout Coos Bay

Partners:

Oregon Institute of Marine Biology; South Slough National Estuarine Research Reserve; Oregon State University; Oregon Sea Grant; Oregon Department of Fish and Wildlife

Timeline:

Sep 2011 to Sep 2013

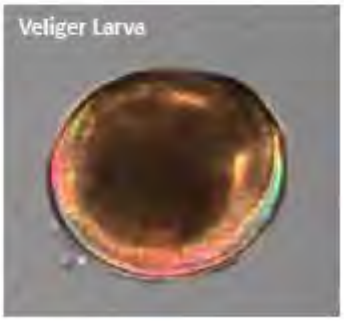
Overview of reproduction:

Olympia oysters *(Ostrea lurida)* are protandrous hermaphrodites. As they mature, each individual begins life as a male, transitioning to female after the first spawning event. Individuals switch their gender after each successive spawning, alternating throughout their life cycle. Adult oysters release their gametes when environmental conditions are favorable, but most notably during seasonal increases in water temperature. Previous research indicates that ~15° C is a critical threshold, and that reproduction is usually limited to late spring, summer, and early fall.

Female Olympia oysters provide a measure of brood protection to their offspring. Male oysters release sperm clusters directly into the water, and they enter the gills of female oysters. Eggs are fertilized internally, and the developing embryos and early larval stages are retained within the shell cavity of the adult female. The brooded larvae develop within the mother's shell for a period of 7-14 days before they are released into the water in the form of swimming veliger larvae. It is estimated that each brooding female may release up to 250,000 veligers.

Investigation of gametogenesis:

The process by which eggs and sperm develop within the ovaries and testes is known as gametogenesis. The gametogenic cycle of *O. lurida* was first described in the 1930s. However, information is very limited about the reproductive cycle of Olympia oyster populations within Coos Bay. Detailed information on gametogenesis and spawning is essential for conservation of Olympia oysters and for the design of effective restoration efforts. In particular, data to describe the timing of spawning, brooding behavior, fecundity, and other life-history traits are critical to develop management strategies to foster self-sustaining populations.



University of Oregon – Oregon Institute of Marine Biology / Charleston, OR

Larval supplies as a critical factor in the recovery of native Olympia oysters in Coos Bay

Cate Pritchard, Oregon Institute of Marine Biology

Project Title:
A collaborative approach to address reproduction, larval supplies, and settlement during recovery of native Olympia oysters

Location:
Coos Bay, Oregon

Goal:
Generate new science to support development of a conservation and recovery plan for Olympia oyster populations throughout Coos Bay

Partners:
Oregon Institute of Marine Biology; South Slough National Estuarine Research Reserve; Oregon State University; Oregon Sea Grant; Oregon Department of Fish and Wildlife

Timeline:
Nov 2011 to Sep 2013

Larval supply of Olympia oysters (*Ostrea lurida*) along a marine-estuarine gradient in the Coos Bay Estuary

Several factors may pose limitations to the recovery of Olympia oyster populations in Coos Bay. A few possibilities include limited larval supply, inadequate substrate for settlement (either limited by area or type), and environmental conditions that result in high larval mortality or low settlement. To examine which mechanisms are at play, we have taken a reductionist approach and are currently trying to understand a number of smaller patterns and relationships, which we will then combine to offer suggestions on future site selection for restoration of *O. lurida*, to promote self-sustaining populations. Using a combination of passive larval traps (see right) and settlement plates at 5 sites along a marine-estuarine gradient in the Coos Bay estuary, we will try to answer the following questions: (1) *are early- and late-stage larvae supplied equally throughout the estuary?* (2) *are early- and late-stage larvae supplied to areas outside the range of adult oysters?* (3) *can water quality parameters such as temperature or salinity be used to predict larval abundance?*

Coos Bay Estuary. Yellow points show sample sites, and the blue band illustrates salinity and temperature gradients. Marine sites are characterized by low temperatures and high salinity, and Riverine sites are characterized by high temperatures and lower salinities. Orange sites indicate no known adult populations of Olympia oysters; yellow indicate areas with known adult oysters.

Larval traps (white cylinders) and settlement plates (white squares). Traps and plates were deployed and collected bimonthly, mid-July 2012 through mid-November 2012.

Are early and late-stage larvae supplied equally throughout the estuary?

Traps collected between mid-July 2012 and mid-September 2012 indicate that neither early nor late-stage larvae were supplied equally throughout the estuary. Both stages of larvae exhibited peak abundance during the first sampling period (July 19-Aug 2), and the greatest abundance of both stages occurred at the Downtown Coos Bay study site. Early-stage larvae were most abundant at Coalbank Slough, followed by Catching Slough, Haynes Inlet, and Empire. Late-stage larvae were most abundant in Downtown Coos Bay, followed by Haynes Inlet, Coalbank Slough, Catching Slough, and Empire. These patterns of larval abundance within stages and between sites continued for the remainder of the sampling season. It was common to observe no early-stage larvae or late-stage larvae in the samples collected from Empire. These preliminary results indicate that early- and late-stage larvae are not supplied equally throughout the estuary.

University of Oregon – Oregon Institute of Marine Biology / Charleston, OR

Larval settlement and post-settlement mortality as determinants of the spatial distribution of Olympia oysters in Coos Bay

Rose Rimler, Oregon Institute of Marine Biology

Project Title:

A collaborative approach to address reproduction, larval supplies, and settlement during recovery of native Olympia oysters

Location:

Coos Bay, Oregon

Goal:

Generate new science to support development of a conservation and recovery plan for Olympia oyster populations throughout Coos Bay

Partners:

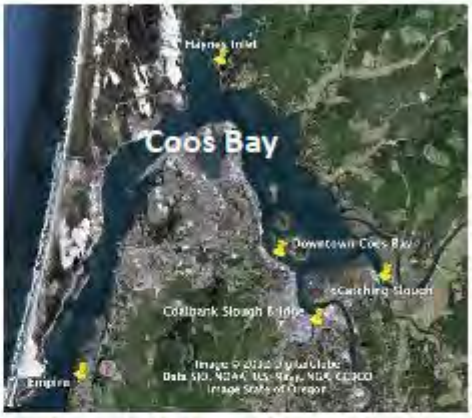
Oregon Institute of Marine Biology; South Slough National Estuarine Research Reserve; Oregon State University; Oregon Sea Grant; Oregon Department of Fish and Wildlife

Timeline:

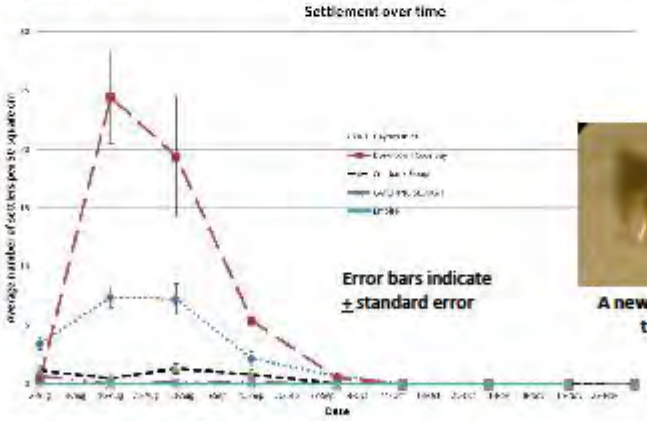
Nov 2011 to Sep 2013

Monitoring settlement throughout Coos Bay:

"Where do Olympia oyster larvae settle in Coos Bay?" Beginning in late July 2012, we placed ceramic settlement tiles in the low intertidal zone at five sites throughout Coos Bay. Every two weeks, we retrieved the tiles and replaced them with a second set. The tiles were examined in the laboratory to look for microscopic oyster settlers. At each site, we continuously monitored temperature, salinity, and water level. We are currently analyzing the data to compare the dynamics of ambient water parameters with patterns in oyster larval settlement at each site. We simultaneously monitored the abundance of Olympia oyster larvae in the plankton with larval traps placed adjacent to the settlement tiles.



Settlement of Olympia oyster larvae was monitored at five sites throughout Coos Bay



A newly settled oyster in the laboratory

The greatest number of oyster larvae settled in August at the Downtown Coos Bay study site where we counted between 20-25 settlers per 50 sq. cm on the ceramic tiles. Intermediate numbers of settlers were observed at Haynes Inlet, and a few settlers occurred at Coalbank Slough and Catching Sough. No settlers were observed at the Empire study site. Monitoring of oyster settlement was terminated in November with the onset of winter storms.